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Invited Paper

New Two-Domain TN/LCD with Identical, Symmetrical and ±80° Viewing Cone in Left, Right, Up and Down Viewing Zones

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ABSTRACT

We invented a new two-domain TN/LCD with excellent viewing performance with identical, symmetrical 160° (±80°) viewing cone in all four major viewing zones. The display also showed excellent color tracking and no gray scale reversal. Each sub-pixel is twisted nematic (TN) based with the LC alignments oriented in the horizontal and vertical directions. This is different from the conventional TN/LCD where the LC alignments are oriented in the two diagonal directions. In this special two-domain TN/LCD, the two sub-pixels show complementary asymmetrical horizontal and vertical viewing zones. Thus the combined two-domain effects show symmetrical and identical optical performances in the four major viewing zones. The viewing angle and display performances can be further improved by optical compensation films, in particular, the combination of types A and C films to enlarge the viewing angles in the diagonal viewing directions.

Keywords: LCDs, two-domain, viewing angle improvement, compensation film.

1. INTRODUCTION

The limited viewing angle cone and asymmetrical viewing angle are two of the major limitations of the present LCD's. [1] Various LCD structures have been developed to improve the LCD viewing angle cone and to change the asymmetrical viewing angle to symmetrical viewing angle. In general, the improvement results in lower yield, lower optical transmission, and higher cost. Major improvements methods include 2-domain and 4-domain LCDs, in-plane switching (IPS), optical compensation bend cell (OCB or Pi-cell), fringe field switching, multi-domain vertical aligned (MVA), and film compensation method.[1]

At present, IPS[2] and MVA[3] LCDs offered better viewing angle performance than the two-domain TN/LCDs. However, IPS and MVA have their own weakness and needed some major improvements to have visual performances comparable to CRT. Their optical transmissions are lower and the respond times are longer than those of the standard TN/LCDs.

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Multi-domain TN/LCD offered major advantages by a TN based LCD mode, in comparison to IPS and MVA.[1, 4] Thus the huge material technology, extensive device technology and manufacturing knowledge and know-how can be directly applied to this device fabrication and improvement. However, 2-domain TN/LCD viewing angle is still limited and inferior to the IPS and MVA. 4-domian TN/LCD offered a better viewing angle characteristics, but the cost is higher by the lower yield factor and much complex in the process, and optical aperture is further reduced and had not been used in actual production.

In this paper, we invented a new two-domain TN/LCVD with excellent optical performance, with identical symmetrical and ±80° viewing cone in left, right, up and down viewing zones. The display also showed no gray scale reversal and has excellent color tracking. For the standard TN/LCDs, the LC is oriented in two diagonal (135° and 45°) directions. In the standard 2-domain TN/LCDs, a pixel is divided into two sub-pixels, one with 135°/45° and the second with 315°/225°. For this special two-domain TN/LCD, the LC is oriented in two horizontal and vertical (0° and 90°) directions; each pixel is divided into two sub-pixels; one with rubbing angle is 90° to 0° rotations, and the second sub-pixel with 270° to 180°. Each sub-pixel is a TN based with complementary asymmetrical horizontal and vertical viewing zone. The display performance can be further improved by optical compensation films, in particular, the combination of types A and C films to enlarge the viewing angles in the diagonal viewing directions. In this paper, we will present only the modeling results. The cell fabrication for this special two-domain TN/LCD is in progress and the experimental results will be reported when it is completed.

In the following discussion, we will review in Section 2 the optical performances for the standard one-domain and two-domain TN/LCDs. In Section 3, we discuss the optical performances for this new two-domain TN/LCD. We use two LC materials, one for the standard first minimum LC (Merck MLC-9000-100) with an operation cell gap of about 5um, and one high optical birefringence LC (Merck TL-203) with an operation cell gap of about 2um for fast response applications.

2. STANDARD ONE DOMAIN AND TWO DOMAIN TN/LCDS

2.1. Standard Single-Domain TN/LCDs

In the following discussion, we define the x-axis in the horizontal direction, and y-axis in the upper vertical direction. We use the standard spherical polar coordinate system where for the viewing azimuthal angle, 0°, 90°, 180°, and 270° are refereed to as right, up, left and down viewing zones respectively.

For the standard TN/LCDs, LC is oriented in 135°/45° direction. Only the horizontal (left-right) viewing angle zone offers a symmetrical viewing angle, and all other viewing angle zones are asymmetrical. In particular, the vertical (up-down) is not symmetrical and the lower zone optical performance is better than that for the upper zone.

In the following discussion, we use two LCs for examples. First, we consider Merck TL-203 with an Δn (=ne-no) = 0.2013. The material parameters are as follows: $\varepsilon\perp$= 4.2, $\varepsilon//$ = 15.2, k11=15.8pN, k33 = 17.9pN, V10 = 1.92V and V90 = 2.62 V. By the operation voltage, k22 is estimated to be k22=8.5pN. TL-203 is an appropriate material for fast response and large viewing angle LCD applications. The optimal cell gap with a large viewing angle is about 2um, which offers a fast time response. Second, we consider Merck MLC-9000-100 with a standard Δn = 0.1137. The material parameters are as follows: $\varepsilon\perp$= 4.2, $\varepsilon//$ = 12.4, k11=11.3pN, k22= 6.1pN, k33 = 14.3pN, V10 = 1.42V and V90 = 2.23 V. MLC-9000-100 is an appropriate material for low voltage and large viewing angle LCD applications. The optimal cell gap with a large viewing angle is about 4-5um.

The display performances for the TN/LCD with 2um TL-203 are shown in Figures 1-6. Figures 1-3 show the transmission vs. voltage and viewing angle in the horizontal and vertical viewing angle zones respectively. For

the horizontal viewing angle, left and right viewing angles are symmetrical where the optical response for a positive viewing angle +θ is the same for the optical response for the corresponding negative viewing angle -θ. For the vertical viewing angle, the up and down viewing angles gave a different and asymmetrical viewing angle performances. Figures 4 and 5 show the standard TN/LCD transmission versus viewing angle and gray scale level for horizontal and vertical viewing zones with an 8-gray level operation. Good performances are shown in the horizontal viewing zone with a viewing cone of 100° (±50°) for contrast ratio CR=5, and 80° (±40°) for CR=10; and poor performances are shown in the vertical viewing zone with a viewing cone of 100° (+35 to -64°) for CR=5, and 90° (+27 to -54°) for CR=10. The viewing angle can be improved by Nitto C-plate with a vertically oriented optical axis and negative birefringence (ne-no<0) film, a FujiFilm, with an inhomogeneous oriented negative birefringence film, and also type A and O films, and ROLIC film.[1, 5, 6, 7] Figure 6 shows the standard TN CR contour plot at 5.0 volt, without any additional optical compensation film. The viewing angle cone is summary in Table 1.

Table 1. Comparison of TN/LCDs viewing angle cones.

o-mode TN/LCD	Horizontal zone (CR=5)	Horizontal zone (CR=5)	Vertical zone (CR=5)	Vertical zone (CR=5)
1-domain TN/LCD	±50°	±40°	+35°/-64°	+27°/-54°
Standard 2-domain TN/LCD	±50°	±40°	±43°	±34°
Special 2-domain TN/LCD	>±80°	>±80°	>±80°	>±80°

2.2. Standard Two-Domain TN/LCDs

In the standard 2-domain TN/LCDs, a pixel is divided into two sub-pixels, one with 135°/45° and the second with 315°/225° LC alignment. This geometry has the same left-right viewing zones in each sub-pixel, only the up and down are in the reverse. In the standard 2-domain TN/LCD, the left-right zone is the same as those for the single-domain TN/LCD, and the up-down becomes the averaged value of up and down in the single domain TN/LCD.

The display performances for the standard two-domain TN/LCD with 2um TL-203 are shown in Figures 1, 4, and 7-9. Figures 1 and 7 show the transmission versus voltage and viewing angle in the horizontal and vertical viewing angle zones respectively. For the horizontal viewing angle zone, one-domain and two-domain TN/LCD have the same performance, where left and right viewing angle are symmetrical. For the vertical viewing angle, as shown in Figure 7, for the two-domain, the up and down viewing zone show a symmetrical optical performance. Figures 4 and 8 show the standard two-domain TN/LCD transmission vs. viewing angle and gray scale level for horizontal and vertical viewing zones. Good performance is shown in the horizontal viewing zone with a viewing cone of 100° (±50°) for CR=5, and 80°(±40°) for CR=10. An improved symmetrical performance is shown in the vertical viewing zone with a viewing cone of 86° (±43°) for CR=5, and 68° (±34°) for CR=10. The viewing angle can be improved by Nitto C-plate with a negative birefringence film.[8] Figure 9 shows the standard two-domain TN CR contour plot at 5.0 volt. The viewing angle cone is summarized in Table 1.

Since these four viewing angle zones have a narrow viewing cone in the single domain TN/LCD, the resulting 2-domian TN have a limited viewing angle, and the vertical viewing zone is different with horizontal viewing zone. The results are summarized in Table 2.

Figure 1. Standard one-domain and two-domain TN/LCD transmission vs. voltage for normal incident, ±15°, ±30°, and ±45° in the horizontal viewing zone. LC: TL-203.

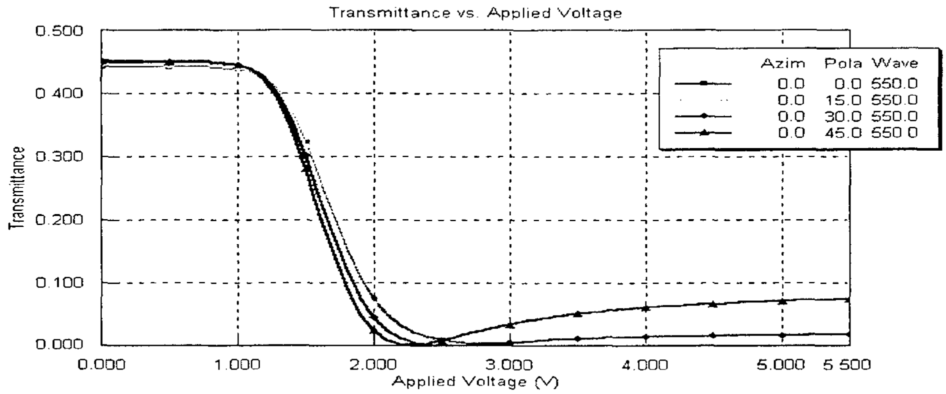


Figure 2. Standard one-domain TN/LCD transmission vs. voltage for normal incident, +15°, +30°, and +45° in the vertical viewing zone. LC: TL-203.

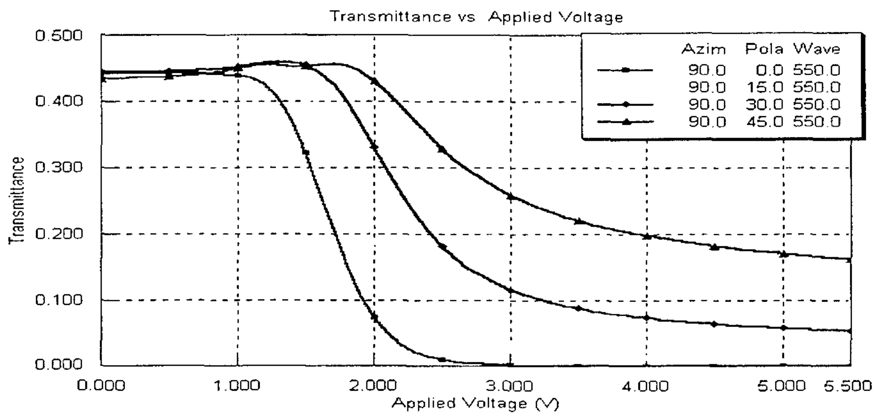


Figure 3. Standard one-domain TN/LCD transmission vs. voltage for normal incident, -15°, -30°, and -45° in the vertical viewing zone. LC: TL-203.

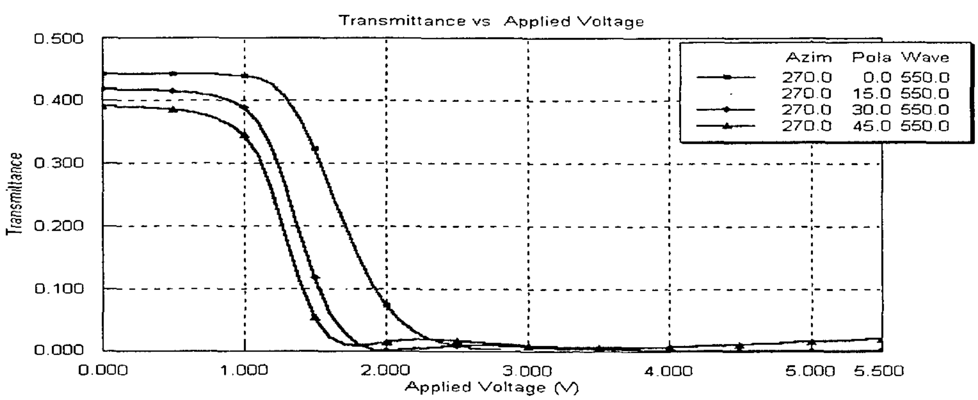


Figure 4. Standard one-domain and two-domain TN/LCD transmission vs. viewing angle and gray scale level for horizontal viewing zone. LC: TL-203.

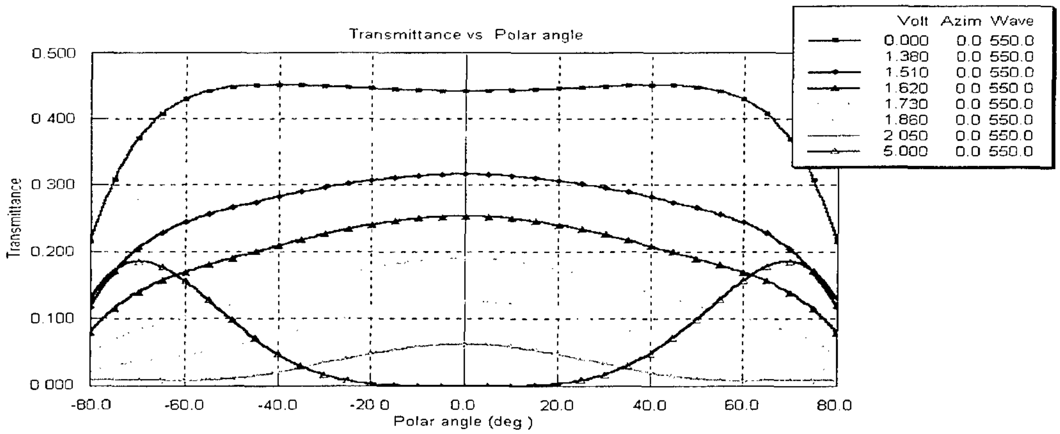


Figure 5. Standard one-domain TN/LCD transmission vs. viewing angle and gray scale level for vertical viewing zone. LC: TL-203.

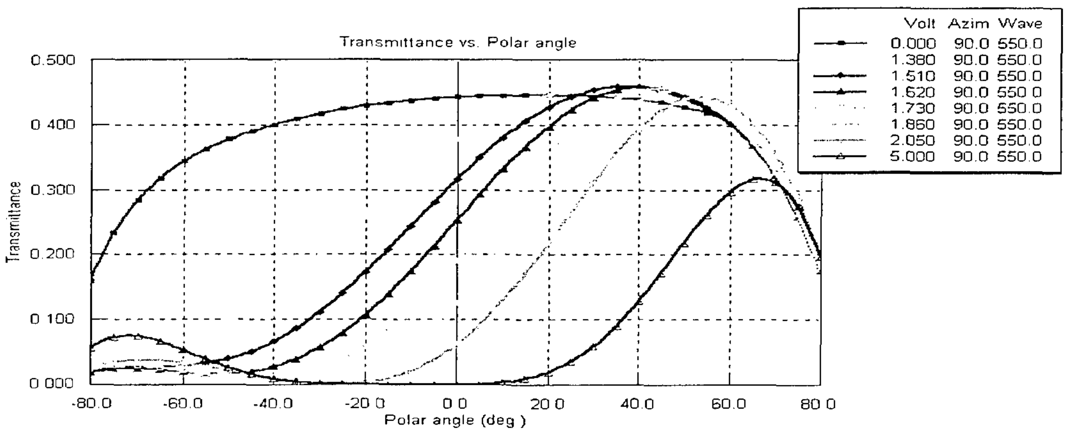
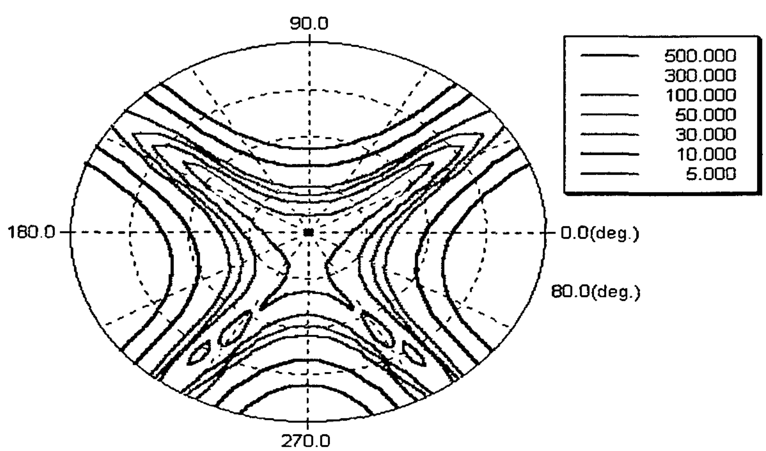


Figure 6. Standard TN CR contour plot at 5.0 volt. LC: TL-203.



Equal contrast ratio contour

Figure 7. Standard two-domain TN/LCD transmission vs. voltage for normal incident, ±15°, ±30°, and ±45° in the vertical viewing zone. LC: TL-203.

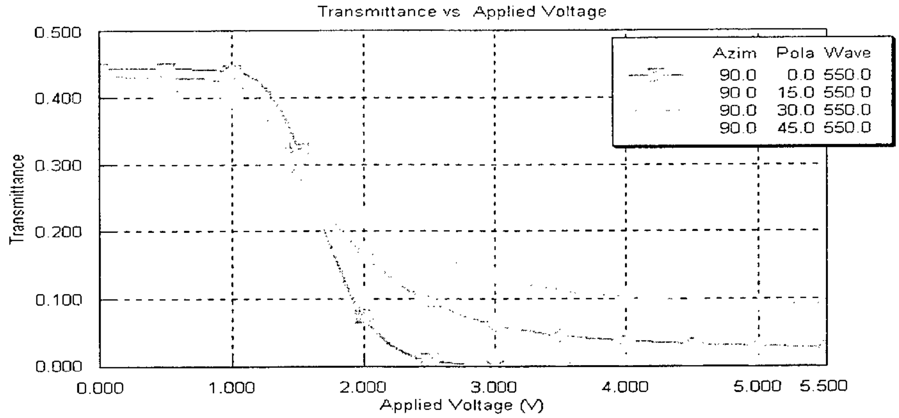


Figure 8. Standard two-domain TN/LCD transmission vs. viewing angle and gray scale level for vertical viewing zone. LC: TL-203.

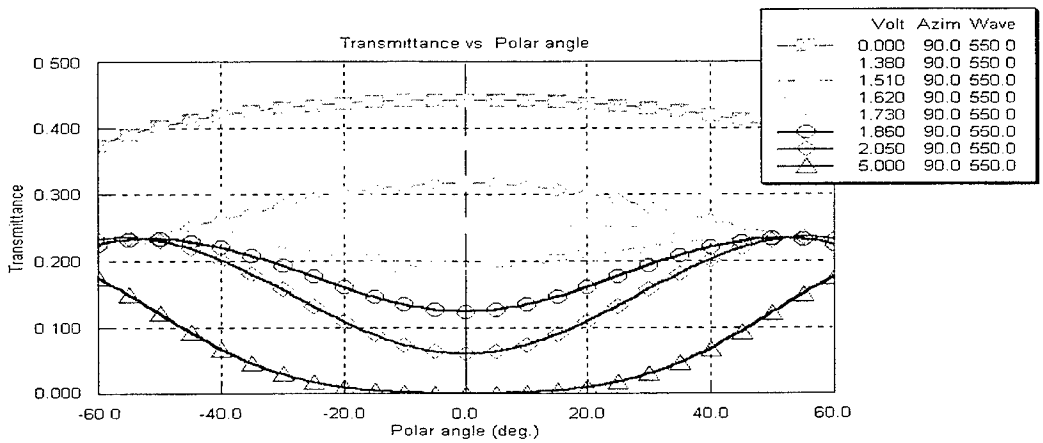


Figure 9. Standard two-domain TN/LCD CR contour plot at 5.0 volt. LC: TL-203.

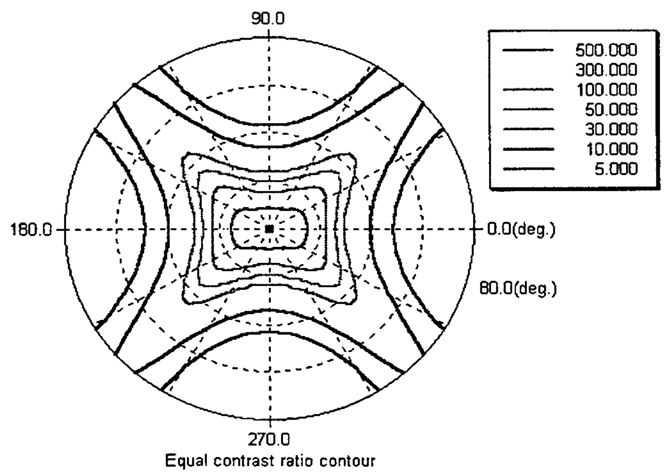


Table 2. Comparison of standard one-domain, 2-domain, 4-doiam and the two-domain TN/LCDs.

	Standard 1-domain TN	Standard 2-domain TN	Standard 4-domain TN	New 2-domain TN
LC director	135°/45°	135°/45°, 315°/225°.	135°/45°, 315°/225°, 225°/135°, 45°/315°.	90°/0°, 270°/180°.
Left-right				
a. symmetrical	Yes	Yes	Yes	Yes
b. viewing cone (CR=5)	±50°	±50°	±45°	±80°
Up-Down				
a. symmetrical	No	Yes	Yes	Yes
b. viewing cone (CR=5)	+35° to –64°	±43°	±45°	±80°
c. = left-right	No	No	Yes	Yes
Aperture ratio	High	Medium	Low	Medium
Gray scale inversion	Yes	Small	No	No
Color tracking	Medium	Medium	Medium	No
Total performance	OK	Good	Good	Excellent

3. SPECIAL TWO DOMAIN TN/LCDS

3.1. Optical Performance for the Special 0/90 Single-Domain TN/LCDs

In the new two-domain TN/LCDs, a pixel is divided into two sub-pixels, one with rubbing along the 90° and 0° directions, the LC follows a 90°rotation from 90°axis to 0°axis, and the second sub-pixel with rubbing along the 270° and 180° directions, the LC follows a 90°rotation from 270°axis to 180°axis. Figures 10 and 11 show the viewing angle characteristics in each sub-pixel for the new two-domain TN/LCD where Figure 10 for 90°/0° direction and Figure 11 for 270°/180°. In each sub-pixel, both the horizontal (left-right) and vertical viewing angle zones are asymmetrical, but with the following important special features:

$$90°/0° \text{ right} = 90°/0° \text{ up} = 270°/180° \text{ left} = 270°/180° \text{ down}, \tag{1}$$
$$90°/0° \text{ left} = 90°/0° \text{ down} = 27°/180° \text{ right} = 270°/180° \text{ up}. \tag{2}$$

Thus this special features form a unique complementary asymmetrical viewing angle properties.

3.2. Optical Performance for the Special 0/90 Two-Domain TN/LCDs

In this special two-domain TN/LCD, we have the unique complementary optical proprieties given in Eqs. (1) and (2). Thus for this special two-domain TN, we have the following special identical symmetrical viewing in these four viewing zones property:

$$\text{right} = \text{up} = \text{left} = \text{down}. \tag{3}$$

The properties (3) offer a unique property in the two-domain TN/LCD where the display exhibits symmetrical and identical optical performances in the four major viewing zones. Also, we have a very large viewing cone of larger than 160° (±80°) with CR=10.

The display performances for this special two-domain TN/LCD with 2um TL-203 and not compensation film are shown in Figures 12-14. Figure 12 shows the transmission vs. voltage and viewing angle in the horizontal and vertical viewing angle zones, with not compensation films. Same identical optical performance is obtained in the horizontal and vertical viewing zones, with left, right, up and down symmetrical performances, where the optical response for a positive viewing angle $+\theta$ is the same for the optical response for a negative viewing angle $-\theta$, in both the vertical and horizontal viewing zones. Figure 13 shows the transmission vs. viewing angle and gray scale level for horizontal and vertical viewing zones. Good performance is shown in both viewing zones with a viewing cone of larger than 180° (±80°) for CR=5 and for CR=10. Figure 14 shows the special two-domain TN/LCD CR contour plot at 5.0 volt. The viewing angle cone is summarized in Table 1. The comparisons with other TN/LCDs are included in Table 2.

3.3. Improvement of the Optical Performance for the Special 0/90 Two-Domain TN/LCDs

The optical performances for this special two-domain TN/LCD can be further improved using film compensation method, including the types A, C, O films, FujiFilm, and ROLIC film. Special arrangement might be necessary for type O and Fuji Films, where the optical axes have tilted orientations. The improvements are mainly to improve the performance at the two diagonal directions (which are the horizontal and vertical directions for the standard 135/45 TN/LCDs).

Two types of optical films are used to improve the optical performances for this special two-domain TN/LCD. First, the C plate, in which the optical axis is homogeneous vertically oriented. Second, the A plate, in which the optical axis is homogeneous parallel oriented. In this study, the optical axis of the A plate is oriented parallel to the LC alignment direction of the adjacent surface. This orientation for the A plate is the same as those used by Yeh and Gu.[7] The optical birefringence of the A and C optical films is negative, where $\Delta n = n_e - n_o < 0$. For each plate, two identical films are used and placed between the entrance polarizer and exit analyzer and placed on both sides of the TN cell, to preserve the left-right viewing symmetry.[7, 9] In the Figure 15, we use A-plate with an optical birefringence thickness[(ne-no) x d] of 120nm. In Figure 16, we use C-plate with an optical birefringence thickness of -160nm. In Figure 17, we use C-plate with an optical birefringence thickness of -80 nm and A-plate with an optical birefringence thickness of -120nm.

The optical films can be used to enlarge the viewing angle performances for this new two-domain TN/LCD. Figures 14-17 show the special two-domain TN CR contour plot at 5.0 volt, with and without optical compensation films. Super large viewing angle is demonstrated. In Figures 14, not optical film is used. The viewing angles along the two diagonal directions are small (these are the viewing angles for the standard two-domain in the horizontal and vertical directions). In Figure 15, we use an A-plate with an optical birefringence thickness of -120nm. In Figure 16, we use a C-plate with an optical birefringence thickness of -160nm. Figures 15 and 16 show that A and C-plates can separately used to enlarge the viewing angle. The combination of A and C plates are used in Figure 17 to further enlarge the viewing angle. In Figure 17, we use C-plate with an optical birefringence thickness of -80 nm and A-plate with an optical birefringence thickness of -120nm. The results showed that the viewing cone at the horizontal and vertical viewing zones are the same for all four cases, i.e., the viewing cones at the four major viewing zones are not affected by the A and C films. But A and C-plates can significantly improved the viewing cones in the two diagonal viewing axes.

Figure 10. Special one-domain TN/LCD with 90/0 LC alignment CR contour plot at 5.0 volt. LC: TL-203.

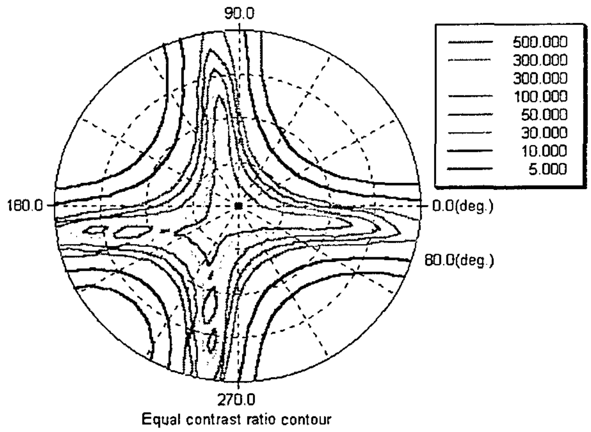


Figure 11. Special one-domain TN/LCD with 270/180 LC alignments CR contour plot at 5.0 volt. LC: TL-203.

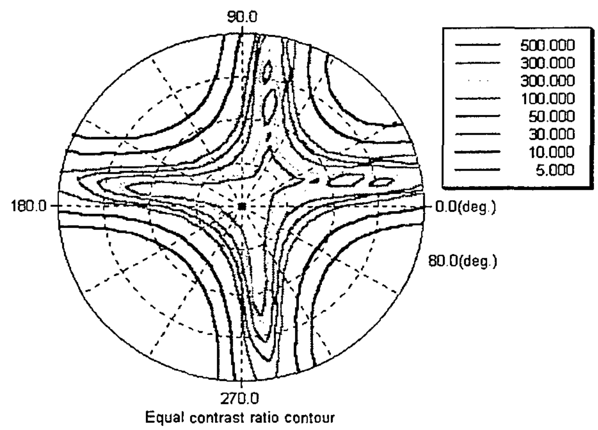


Figure 12. Special two-domain TN transmission vs. voltage for normal incident, ±15°, ±30°, and ±45° in the horizontal and vertical viewing zone with not film. LC: TL-203.

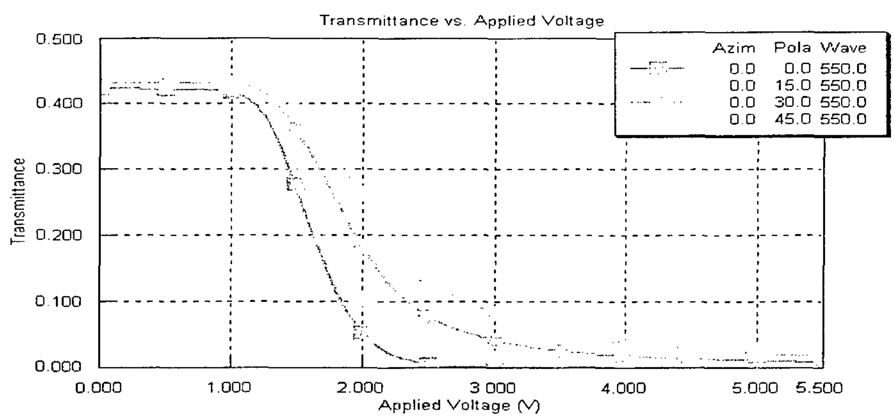


Figure 13. Special two-domain TN transmission vs. viewing angle and gray scale level for horizontal viewing zone with not film. LC: TL-203.

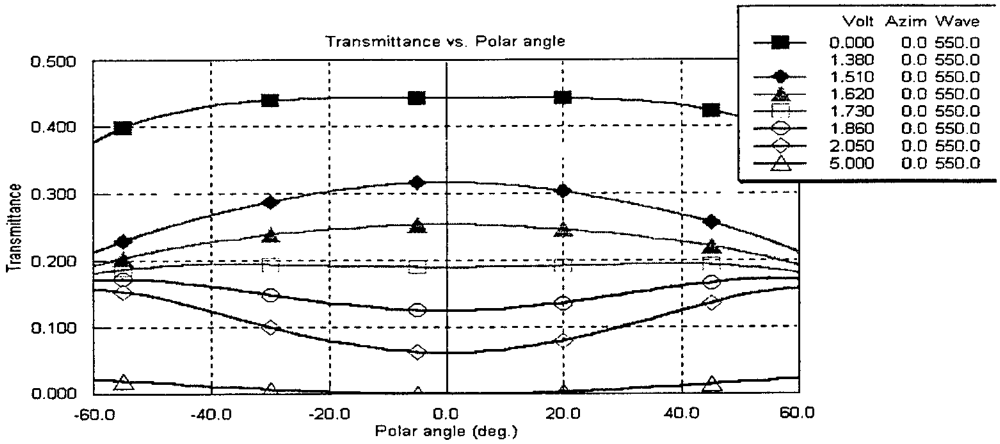


Figure 14. Special two-domain TN CR contour plot at 5.0 volt with not film. LC: TL-203.

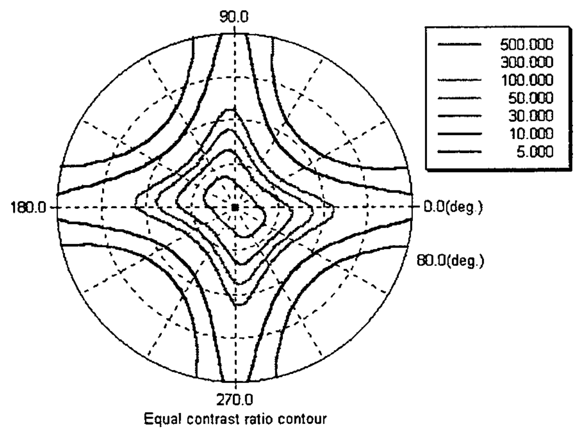


Figure 15. Special two-domain TN CR contour plot at 5.0 volt with A and not C-plates. LC: TL-203.

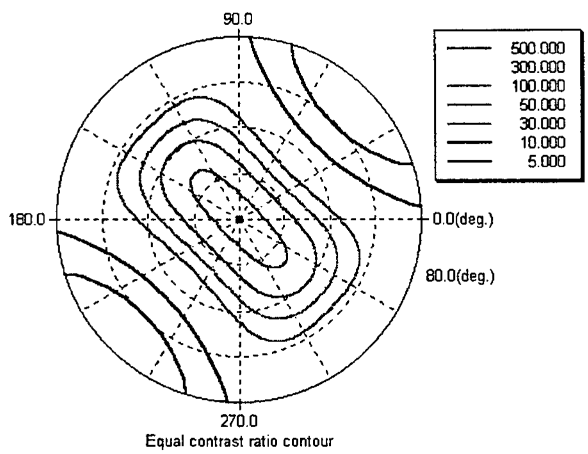


Figure 16. Special two-domain TN CR contour plot at 5.0 volt with C and not A-plates. LC: TL-203.

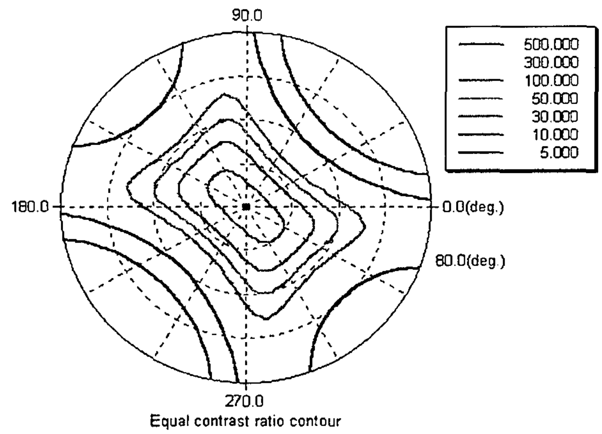
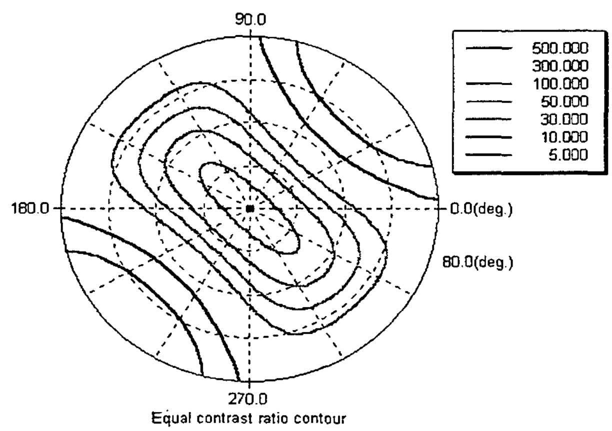


Figure 17. Special 0/90 two-domain TN CR contour plot at 5.0 volt with A and C plates. LC: TL-203.

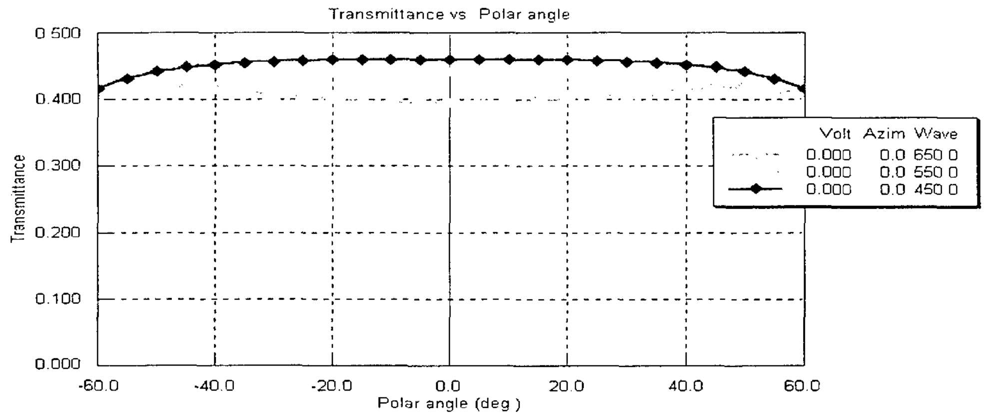


3.4. Improvement of the Color Tracking Performance for the Special 0/90 Two-Domain TN/LCDs

The special two-domain TN/LCDs also offer excellent color tracking. Figures 18-21 show the Red, Green, and Blue transmissions vs. viewing angle and gray scale levels 1 and 8 for horizontal and vertical viewing zones, for the standard one-domain and two-domain TN, and this special two-domain TN/LCD. In the standard one-domain and two-domain TN/LCDs, horizontal viewing zone shows a good color tracking, but poor color tracking appeared in the vertical viewing zone. In comparison to the normal one-domain and two-domain TN/LCDs, this new two-domain TN shows good color tracking.

Figure 18. Normal 135/45 1-domain TN/LCD Red/Green/Blue transmission vs. viewing angle, and gray scale levels No. 1 and 8, for horizontal viewing zone with not films. LC: TL-203.

18(a).



18(b)

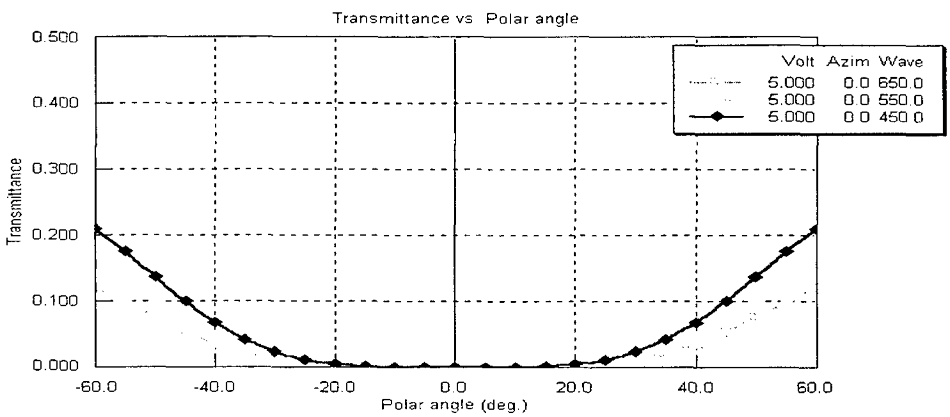
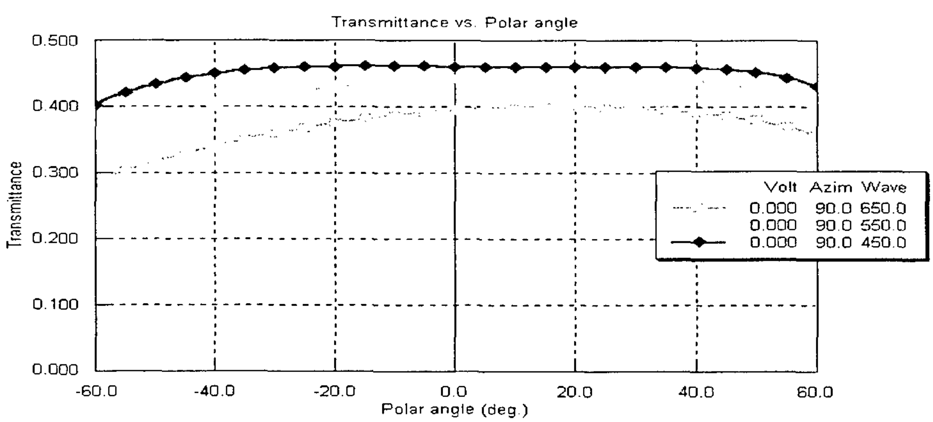


Figure 19. Normal 135/45 1-domain TN/LCD Red/Green/Blue transmission vs. viewing angle, and gray scale levels No. 1 and 8, for vertical viewing zone with not films. LC: TL-203.

19(a)



19(b)

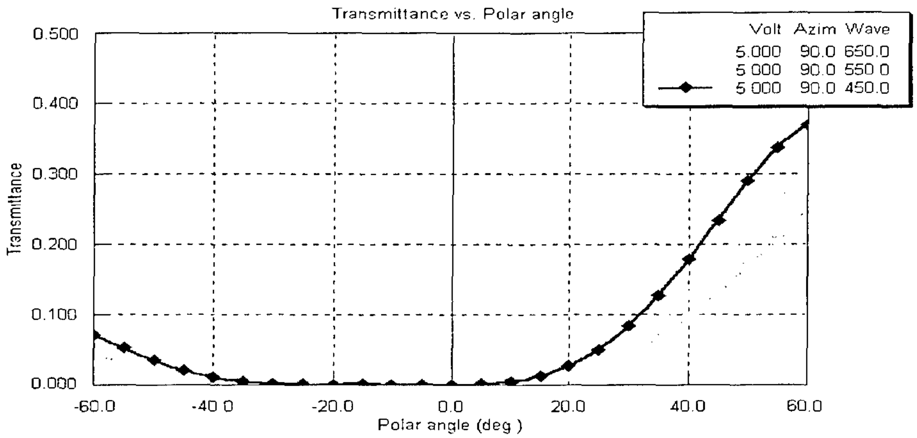
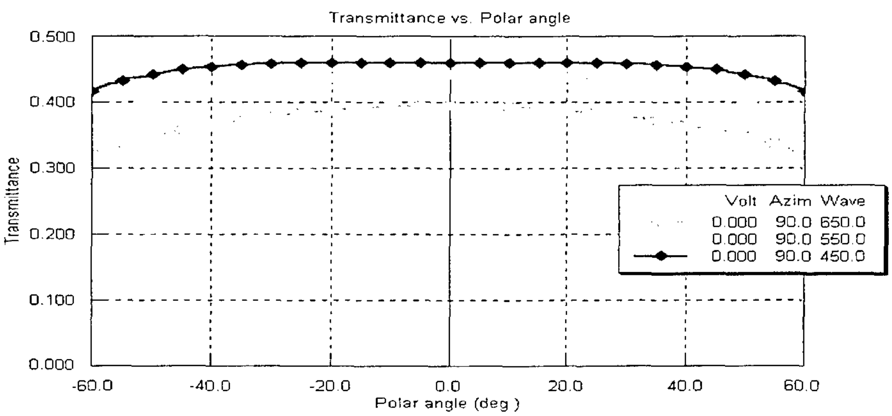


Figure 20. Normal 135/45 two-domain TN/LCD Red/Green/Blue transmission vs. viewing angle, and gray scale levels No. 1 and 8, for vertical viewing zone with not films. LC: TL-203.

20(a)



20(b)

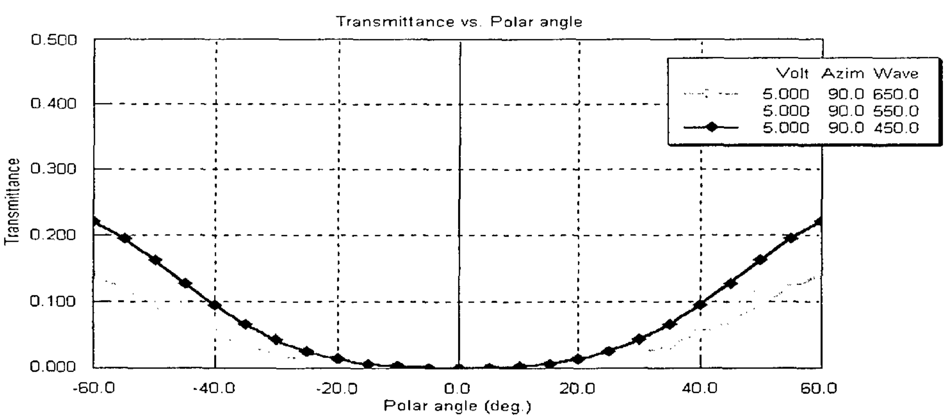
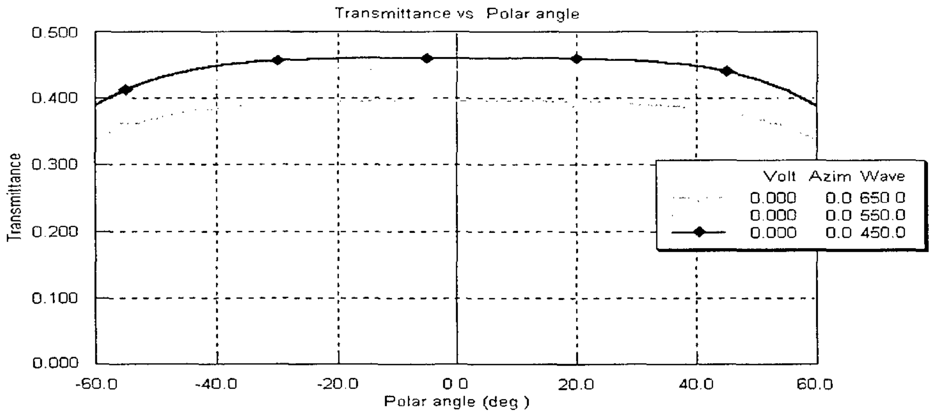
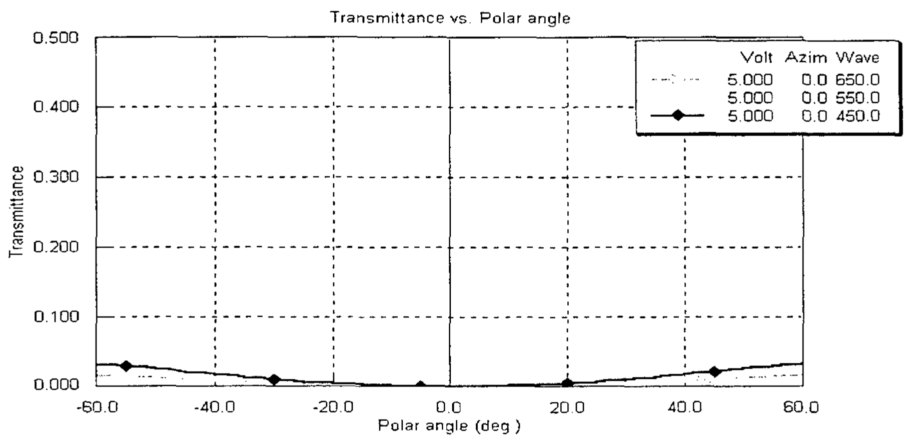


Figure 21. Special 0/90 two-domain TN/LCD Red/Green/Blue transmission vs. viewing angle, and gray scale levels No. 1 and 8, for horizontal viewing zone with A and C plates. LC: TL-203.
21(a)



21(b)



3.5. Improvement of the Optical Performance for the Special 0/90 Two-Domain TN/LCDs with Normal First minimum LC

The improvement of the optical performance for the special 0/90 two-domain TN/LCDs with a normal first minimum LC are shown in Figures 22-24 for MLC-9000-100. MLC-9000-100 is an appropriate material for low voltage and large viewing angle LCD applications. The optimal cell gap with a large viewing angle is about 4um. Again, the new two-domain TN/LCD show excellent viewing performance with identical, symmetrical 160° (±80°) viewing cone in all four major viewing zones. The display also showed excellent color tracking and no gray scale reversal.

4. CONCLUSION

We invented a new tow-domain TN/LCD with excellent viewing angle performances, where identical, symmetrical 160° (±80°) viewing cone appeared in all four major viewing zones. The new two-domain TN/LCD also offer no gray scale reversal and excellent color tracking.

The wide viewing TN/LCD should be important for the viewing angle LCDs, with major application for notebook PCs, monitor, and PFDA application. This result showed that with TN/LCDs, the viewing angle could be significantly improved and comparable to the advanced IPS and MVA LCDs viewing angle. This is a TN based LCD and make it attractive for AMLCDs having TN/LCDs as the standard LCD.

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Figure 22. Standard one-domain TN/LCD CR contour plot at 5.5 volt. LC: MLC-9000-100.

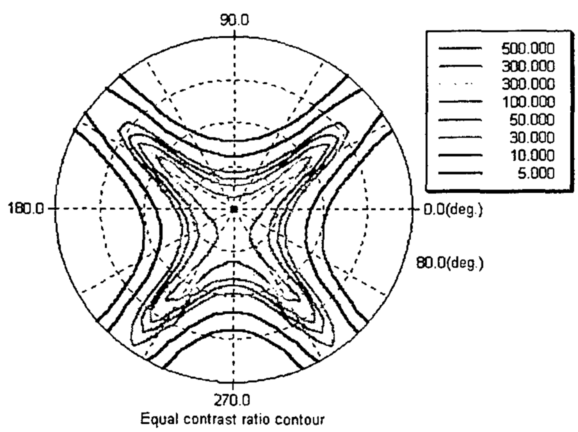

Figure 23. Standard two-domain TN/LCD CR contour plot at 5.5 volt. LC: MLC-9000-100.

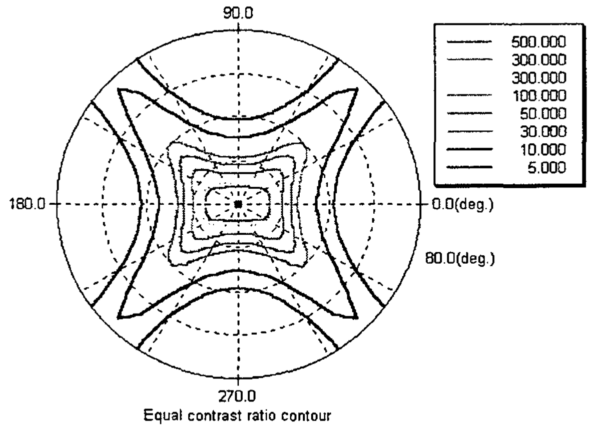

Figure 24. Special two-domain TN/LCD CR contour plot at 5.5 volt with A and C-plates. LC: MLC-9000-100.